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FAST LUMINOSITY MONITORING USING DIAMOND SENSORS FOR SUPER FLAVOUR FACTORIES

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Abstract

Super flavor factories aim to reach very high luminosities thanks to a new concept whereby the ultra-low emittance beams collide with a large crossing angle. Fast luminosity measurements are needed as input to luminosity optimisation and feedback in the presence of dynamic imperfections. The required small relative precision can be reached exploiting the very large cross section of the radiative Bhabha process at zero photon scattering angle. The instrumental technique selected to sustain the large particle fluxes is based on diamond sensors to be positioned via moveable stages immediately outside the beam pipe, at locations chosen to minimise the contamination from other particle loss mechanisms.

INTRODUCTION

The next genereration of Flavor Factories will require very high luminosity asymmetric electron-positron beam collisions. In particular, the SuperKEKB project [1], dedicated to B meson physics study experiment (Belle II) [2], is presently being designed for construction at KEK (Japan). It consists of a double-ring collider with a 4 GeV positron beam and a 7 GeV electron beam. The very high luminosities, of order 10^{35} to 10^{36} $cm^{-2}s^{-1}$ can be achieved thanks to a new concept proposed by P. Raimondi [3], whereby the ultra-low emittance beams collide with a large crossing angle, enabling the effective interaction region to be significantly shortened longitudinally and the β^* parameters to be correspondingly reduced without severe beam blow-up. In this type of ring, beams have relatively short lifetimes of order ten minutes, mainly due to the rate of the Touschek large angle intrabeam Coulomb scattering, as well as of the zero angle radiative Bhabha scattering, and must therefore be continuously re-injected.

Fast luminosity measurements are needed as input to luminosity optimisation and feedback in the presence of dynamic imperfections. The specifications are a relative precision of 10^{-2} to 10^{-3} within 1 to 10 msec, with a contamination from non-luminosity scaling contributions smaller than 1%. This can be achieved exploiting the very large cross section of the radiative Bhabha process at zero photon scattering angle. To cover a large range of luminosities, from low values achieved during initial tuning to the highest ones, the photons and scattered electrons and positrons on both sides of the collision point need to measured. In the case of the scattered electrons/positrons, separation from the main beam is achieved selecting locations after the first bending magnets downstream of the interaction region. The criteria used are a large enough horizontal dispersion function together with small values of the β function, in order to deflect a signicant part of these low energy Bhabha electrons/positrons while at the same time limiting potential Touschek losses. The instrumental technique selected to sustain the large particle fluxes is based on diamond sensors (Fig. 1) to be positioned via moveable stages immediately outside the beam pipe, on the low energy side.

Figure 1: Diamond sensor.

A study, started at LAL in the context of the SuperB project [3] and now pursued for SuperKEKB, aims to develop the corresponding instrumentation and methodology needed for such fast luminosity monitoring. We will expose in the following the first results of this work and the plans for the next three years, within the commissioning period of SuperKEKB.

PRELIMINARY RESULTS

The radiative Bhabha scattering represents a main source of backgrounds via particles losses, as well as a limitation for beam life time. However this process can also be useful for luminosity monitoring since the amount of scattering is large and proportionnal to the luminosity. The radiative Bhabha process at zero photon angle (Fig.2) corresponds to an electron-positron beam particles scattering through the exchange of a quasi-real photon at almost zero angle. It can also be understood as a Compton scattering convoluted with a spectrum of quasi-real photons (equivalent photon approximation).

The Bhabha events have been generated using two simulations: BBBREM [4] which is a dedicated Monte-Carlo simulation for the radiative Bhabha process at very small angle, and GUINEA-PIG++ [5], a beam-beam interaction simulation mainly used for high energy e^+e^- collider studies, in which the radiative Bhabha process at very small angle is treated as a Compton scattering process convoluted with a spectrum function for the quasi-real photons. The cross section, calculated at the $\Upsilon(4S)$ center

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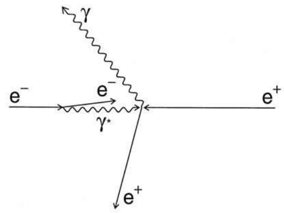

Figure 2: Radiative Bhabha process at zero photon angle.

of mass energy, with a photon energy cut set to $1\%.E_{beam}$, is about 270 mbarn, similar for both simulations, which take both into account the correction for very small transverse size beams (beam-size effect) [6]. Energy and angular distributions have also been compared and cross-checked.

The scattered electrons/positrons have then been tracked in the SuperB lattice, up to 20 meters downstream of the interaction point, using the MAD8 code [7], in order to estimate the rates deflected enough to hit the beam pipe and thus potentially generating signals in a $5 \times 5\ mm^2$ diamond sensors placed immediately outside the beam pipe, at 2.5 cm distance from the beam. Three locations have been considered, after the first, second and third bending magnets, where the separation with the main beam is maximal. The top part of the figure 3 shows the transverse profile of the LER Bhabha distribution (in blue), compared to the beam one (in red), after the second magnet ; the bottom part displays the horizontal extension on the Bhabha particles as a function of their energy, at the same location.

To reach a relative precision of 10^{-3} in 10ms, and considering a luminosity of $10^{35} cm^{-2} s - 1$, at least 10^6 Bhabha events have to be detected, which represents 3×10^{-3} of the produced Bhabha events. This ratio can be obtained after the second and the third bending magnets, as shown in Table 1.

Table 1: Fraction of Bhabha particles hitting the sensor.

Location	LER	HER
1^{st}bending magnet	2.0×10^{-3}	1.0×10^{-2}
2^{nd}bending magnet	2.9×10^{-2}	3.4×10^{-2}
3^{rd}bending magnet	4.6×10^{-2}	4.4×10^{-2}

GEANT4 simulations with realistic representations of materials and geometries are required to predict the actual number of particles which will hit the diamond sensor and the resulting signals, taking into account the interactions of the scattered charged particles with the material of the beam pipe, which can induce large electromagnetic showers as illustrated on figure 4. A preliminary study indicates that the number of hits in the sensor will be dominated by the secondaries. One Bhabha particle can indeed generate a shower of hundreds of particles, due to its very small incident angle into the material of the beam pipe. On figure 5

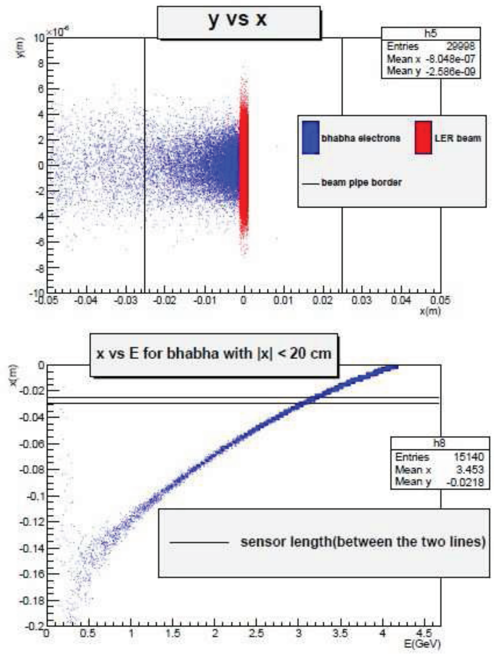

Figure 3: On the top part: Transverse profil of the Bhabha (in blue) compared to beam (in red) after the second bending magnet in the LER. On the bottom part: horizontal extension of Bhabha Vs their energy. Black lines represent the position of the sensor.

is shown a first estimation of the rate of particles outside the beam pipe in a transverse plane situated just after the second bending magnet. The second hot spots on the LER side, situated at 2 cm from the edge of the beam pipe, corresponds to the primary Bhabha photons. The corresponding energy depositions are displayed on figure 6.

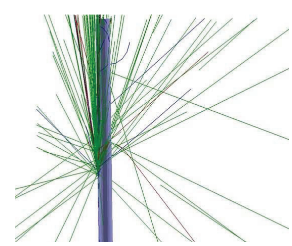

Figure 4: Electromagnetic shower induced by one primary electron of 3.4 GeV interacting with the material of the beam pipe at shallow angle.

NEXT PLANS

The above described study is now being repeated for the SuperKEKB/Belle II experiment, in the context of a Ph.D. thesis project to start in Fall 2013. Following the same procedure as for SuperB, the location for the positioning of the luminosity monitors will be identified, using the SAD tracking code [8], considering optics as well as potential backgrounds, in particular from Touschek particle

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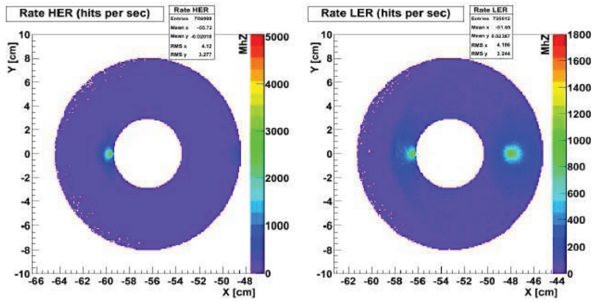

Figure 5: Rate of particles outside the beam pipe after the second bending magnet in the HER on l.h.s. and the LER on r.h.s.

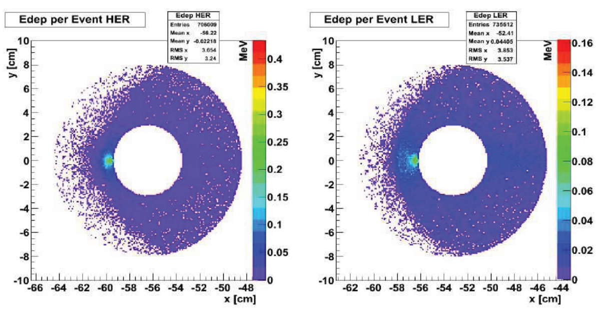

Figure 6: Particle energy deposition outside the beam pipe after the second bending magnet in the HER on l.h.s. and the LER on r.h.s.

losses. An advanced study of secondaries induced be interactions of the Bhabha particles with the beam pipe material is also required to quantify precisely the expected detector signals and optimize the geometries and the positioning with respect to the magnets. The design of the diamond sensor instrumentation and the suitable electronics readout to sustain and measure the large expected particle flows will be performed in collaboration with the ATF2 diamond sensor project [9]. The realisation of a first prototype is planned for next year, with initial testing at the PHIL low energy beam line at LAL. Discussions with SuperKEKB partners are on-going for integration of the planned prototype among the instrumentation for the early commissioning at KEK in the first semester of 2015, both before and after installation of the Belle-II detector at the collision point. More theortical aspects must also be in pursued, in particular the investigation of corrections of the radiative Bhabha cross-section calculation at zero scattering angle for very small transverse size beams.

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